

IN THE CLAIMS

Please amend claims 1, 2, 4, 17 and 20, and add claims 21-25 as follows:

1 1. (Currently Amended) A linear method for performing head
2 motion estimation from facial feature data, the method comprising
3 the steps of:

4 obtaining a first facial image and detecting a head in said
5 first image;

6 detecting position of not more than four points P of said
7 first facial image where $P = \{p_1, p_2, p_3, p_4\}$, and $p_k = (x_k, y_k)$;

8 obtaining a second facial image and detecting a head in said
9 second image;

10 detecting position of not more than four points P' of said
11 first facial image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k)$; and,

12 determining the motion of the head represented by a rotation
13 matrix R and translation vector T using said points P and P' .

1 2. (Currently Amended) The linear method of claim 1, wherein
2 said four points P of said first facial image and said four points

3 P' of said second facial image include locations of outer corners
4 of each eye and mouth of each respective first and second facial
5 images.

1 3.(Original) The linear method of claim 1, wherein said head
2 motion estimation is governed according to:

3 $\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}$, where $R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$ and $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$ represent camera

4 rotation and translation respectively, said head pose estimation
5 being a specific instance of head motion estimation.

1 4.(Currently Amended) ~~The linear method of claim 3 A linear~~
2 method for performing head motion estimation from facial feature
3 data, the method comprising the steps of:

4 obtaining a first facial image and detecting a head in said
5 first image;

6 detecting position of four points P of said first facial image
7 where P = { $\mathbf{p}_1, \mathbf{p}_2, \mathbf{p}_3, \mathbf{p}_4$ }, and $\mathbf{p}_k = (x_k, y_k)$;

8 obtaining a second facial image and detecting a head in said
9 second image;

10 detecting position of four points P' of said first facial
11 image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k)\}$; and,
12 determining the motion of the head represented by a rotation
13 matrix R and translation vector T using said points P and P',
14 wherein said head motion estimation is governed according to:

15
$$P'_i = RP_i + T, \text{ where } R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3} \text{ and } T = [T_1 \ T_2 \ T_3]^T \text{ represent camera}$$

16 rotation and translation respectively, said head pose estimation
17 being a specific instance of head motion estimation, and
18 wherein said head motion estimation is governed according to
19 said rotation matrix R, said method further comprising the steps
20 of:

21 determining rotation matrix R that maps points P_k to F_k for
22 characterizing a head pose, said points F_1, F_2, F_3, F_4 representing three-
23 dimensional (3-D) coordinates of the respective four points of a
24 reference, frontal view of said facial image, and P_k is the three-
25 dimensional (3-D) coordinates of an arbitrary point where
26 $P_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

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$$R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$$

$$R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$$

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30 wherein \mathbf{P}_5 and \mathbf{P}_6 are midpoints of respective line segments
31 connecting points $\mathbf{P}_1\mathbf{P}_2$ and $\mathbf{P}_3\mathbf{P}_4$ and, line segment connecting points
32 $\mathbf{P}_1\mathbf{P}_2$ is orthogonal to a line segment connecting points $\mathbf{P}_5\mathbf{P}_6$, and
33 \propto indicates a proportionality factor.

1 5. (Original) The linear method of claim 4, wherein
2 components r_1 , r_2 and r_3 are computed as:

$$\mathbf{r}_2^T (\mathbf{P}_2 - \mathbf{P}_1) = 0$$

$$\mathbf{r}_3^T (\mathbf{P}_2 - \mathbf{P}_1) = 0$$

3

$$\mathbf{r}_1^T (\mathbf{P}_6 - \mathbf{P}_5) = 0$$

$$\mathbf{r}_3^T (\mathbf{P}_6 - \mathbf{P}_5) = 0$$

1 6. (Original) The linear method of claim 5, wherein
2 components r_1 , r_2 and r_3 are computed as:

3 $\mathbf{r}_3 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1)$,

4 $\mathbf{r}_2 = \mathbf{r}_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$

$\mathbf{r}_1 = \mathbf{r}_2 \times \mathbf{r}_3$

1 7. (Original) The linear method of claim 4, wherein

$$\begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \\ \mathbf{0}^T & \mathbf{P}_i^T & \mathbf{0}^T & 0 & 1 & 0 \\ \mathbf{0}^T & \mathbf{0}^T & \mathbf{P}_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}'_i$$

2

3 each point pair yielding 3 equations, whereby at least four
4 point pairs are necessary to linearly solve for said rotation and
5 translation.

1 8. (Original) The linear method of claim 7, further comprising
2 the step of: decomposing said rotation matrix R using Singular
3 Value Decomposition (SVD) to obtain a form $R = USV^T$.

1 9. (Original) The linear method of claim 7, further comprising
2 the step of computing a new rotation matrix according to $R = UV^T$.

1 10. (Original) A linear method for performing head motion
2 estimation from facial feature data, the method comprising the
3 steps of:

4 obtaining image position of four points \mathbf{P}_k of a facial image;

5 determining a rotation matrix R that maps points \mathbf{P}_k to \mathbf{F}_k for
6 characterizing a head pose, said points $\mathbf{F}_1, \mathbf{F}_2, \mathbf{F}_3, \mathbf{F}_4$ representing
7 three-dimensional (3-D) coordinates of the respective four points
8 of a reference, frontal view of said facial image, and \mathbf{P}_k is the
9 three-dimensional (3-D) coordinates of an arbitrary point where
10 $\mathbf{P}_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

11

$$R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$$

$$R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$$

13

14 wherein \mathbf{P}_5 and \mathbf{P}_6 are midpoints of respective line segments
15 connecting points $\mathbf{P}_1\mathbf{P}_2$ and $\mathbf{P}_3\mathbf{P}_4$ and, line segment connecting points
16 $\mathbf{P}_1\mathbf{P}_2$ is orthogonal to a line segment connecting points $\mathbf{P}_5\mathbf{P}_6$, and
17 \propto indicates a proportionality factor.

1 11. (Original) The linear method of claim 10, wherein
2 components r_1 , r_2 and r_3 are computed as:

$$\mathbf{r}_2^T(\mathbf{P}_2 - \mathbf{P}_1) = 0$$

$$\mathbf{r}_3^T(\mathbf{P}_2 - \mathbf{P}_1) = 0$$

3 $\mathbf{r}_1^T(\mathbf{P}_6 - \mathbf{P}_5) = 0$

$$\mathbf{r}_3^T(\mathbf{P}_6 - \mathbf{P}_5) = 0$$

1 12. (Original) The linear method of claim 11, wherein
2 components r1, r2 and r3 are computed as:

3 $r_3 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1)$,

4 $\mathbf{r}_2 = \mathbf{r}_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$

4 $\mathbf{r}_1 = \mathbf{r}_2 \times \mathbf{r}_3$

1 13. (Original) The linear method of claim 12, wherein a motion
2 of head points is represented according to $\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}$

3 where $R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$ represents image rotation, $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$

4 represents translation, and \mathbf{P}'_i denotes a 3-D image position of four
5 points \mathbf{P}_k of another facial image

1 14. (Original) The linear method of claim 13, wherein

2 $\begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \\ \mathbf{0}^T & \mathbf{P}_i^T & \mathbf{0}^T & 0 & 1 & 0 \\ \mathbf{0}^T & \mathbf{0}^T & \mathbf{P}_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}'_i$,

3 each point pair yielding 3 equations, whereby at least four
4 point pairs are necessary to linearly solve for said rotation and
5 translation.

1 15. (Original) The linear method of claim 14, further
2 comprising the step of: decomposing said rotation matrix R using
3 Singular Value Decomposition (SVD) to obtain a form $R = USV^T$.

1 16. (Original) The linear method of claim 15, further
2 comprising the step of computing a new rotation matrix according to
3 $R = UV^T$.

1 17. (Currently Amended) A program storage device readable by
2 machine, tangible embodying a program of instructions executable by
3 the machine to perform method steps for performing head motion
4 estimation from facial feature data, the method comprising the
5 steps of:

6 obtaining a first facial image and detecting a head in said
7 first image;

8 detecting position of not more than four points P of said
9 first facial image where $P = \{p_1, p_2, p_3, p_4\}$, and $p_k = (x_k, y_k)$;
10 obtaining a second facial image and detecting a head in said
11 second image;
12 detecting position of not more than four points P' of said
13 first facial image where $P' = \{p'_1, p'_2, p'_3, p'_4\}$ and $p'_k = (x'_k, y'_k) +$; and,
14 determining the motion of the head represented by a rotation
15 matrix R and translation vector T using said points P and P' .

1 18. (Original) The program storage device readable by machine
2 as claimed in claim 17, wherein said four points P of said first
3 facial image and four points P' of said second facial image include
4 locations of outer corners of each eye and mouth of each respective
5 first and second facial image.

1 19. (Original) The program storage device readable by machine
2 as claimed in claim 17, wherein said head motion estimation is
3 governed according to:

4 $\mathbf{P}'_i = R\mathbf{P}_i + \mathbf{T}$, where $R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$ and $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$ represent

5 camera rotation and translation respectively, said head pose
6 estimation being a specific instance of head motion estimation.

1 20. (Currently Amended) The A program storage device readable
2 by machine ~~as claimed in claim 19,~~ tangible embodying a program of
3 instructions executable by the machine to perform method steps for
4 performing head motion estimation from facial feature data, the
5 method comprising the steps of:

6 obtaining a first facial image and detecting a head in said
7 first image;

8 detecting position of four points P of said first facial image
9 where P = {P₁, P₂, P₃, P₄}, and P_k = (x_k, y_k);

10 obtaining a second facial image and detecting a head in said
11 second image;

12 detecting position of four points P' of said first facial
13 image where P' = {p'₁, p'₂, p'₃, p'₄} and p'_k = (x'_k, y'_k); and

14 determining the motion of the head represented by a rotation
15 matrix R and translation vector T using said points P and P',
16 wherein said head motion estimation is governed according to:

17
$$R = \begin{bmatrix} \mathbf{r}_1^T \\ \mathbf{r}_2^T \\ \mathbf{r}_3^T \end{bmatrix} = \begin{bmatrix} r_{ij} \end{bmatrix}_{3 \times 3}$$
 and $\mathbf{T} = [T_1 \ T_2 \ T_3]^T$ represent

18 camera rotation and translation respectively, said head pose
19 estimation being a specific instance of head motion estimation, and
20 wherein said head pose estimation is governed according to
21 said rotation matrix R, said method further comprising the steps
22 of:

23 determining rotation matrix R that maps points \mathbf{P}_k to \mathbf{F}_k for
24 characterizing a head pose, said points $\mathbf{F}_1, \mathbf{F}_2, \mathbf{F}_3, \mathbf{F}_4$ representing three-
25 dimensional (3-D) coordinates of the respective four points of a
26 reference, frontal view of said facial image-, and \mathbf{P}_k is the three-
27 dimensional (3-D) coordinates of an arbitrary point where
28 $\mathbf{P}_i = [X_i \ Y_i \ Z_i]^T$, said mapping governed according to the relation:

29

30 $R(\mathbf{P}_2 - \mathbf{P}_1) \propto [1 \ 0 \ 0]^T$
 $R(\mathbf{P}_6 - \mathbf{P}_5) \propto [0 \ 1 \ 0]^T$

31
32 wherein P_5 and P_6 are midpoints of respective line segments
33 connecting points P_1P_2 and P_3P_4 and, line segment connecting points
34 P_1P_2 is orthogonal to a line segment connecting points P_5P_6 , and
35 \propto indicates a proportionality factor.

1 21. (New) The program storage device readable by machine as
2 claimed in claim 20, wherein components r_1 , r_2 and r_3 are computed
3 as:

$$\begin{aligned} \mathbf{r}_2^T(\mathbf{P}_2 - \mathbf{P}_1) &= 0 \\ \mathbf{r}_3^T(\mathbf{P}_2 - \mathbf{P}_1) &= 0 \\ \mathbf{r}_1^T(\mathbf{P}_6 - \mathbf{P}_5) &= 0 \\ \mathbf{r}_3^T(\mathbf{P}_6 - \mathbf{P}_5) &= 0 \end{aligned}$$

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1 22. (New) The program storage device readable by machine as
2 claimed in claim 20, wherein components r_1 , r_2 and r_3 are computed
3 as:
4

$$r_3 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1),$$

$$r_2 = r_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$$

$$r_1 = r_2 \times r_3$$

1

1 23. (New) The program storage device readable by machine as
2 claimed in claim 20, wherein

$$\begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \\ \mathbf{0}^T & \mathbf{P}_i^T & \mathbf{0}^T & 0 & 1 & 0 \\ \mathbf{0}^T & \mathbf{0}^T & \mathbf{P}_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}'_i$$

3

4 each point pair yielding 3 equations, whereby at least four
5 point pairs are necessary to linearly solve for said rotation and
6 translation.

24. (New) The program storage device readable by machine as
claimed in claim 23, further comprising the steps of decomposing
said rotation matrix R using Singular Value Decomposition (SVD) to
obtain a form $R = USV^T$.

25. (New) The program storage device readable by machine as
claimed in claim 23, further comprising the steps of computing a
new rotation matrix according to $R = UV^T$.